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Spatial and temporal properties of the illusory motion-induced position shift for drifting stimuli

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Abstract

The perceived position of a stationary Gaussian window of a Gabor target shifts in the direction of motion of the Gabor's carrier stimulus, implying the presence of interactions between the specialized visual areas that encode form, position, and motion. The purpose of this study was to examine the temporal and spatial properties of this illusory motion-induced position shift (MIPS). We measured the magnitude of the MIPS for a pair of horizontally separated (2 or 8 deg) truncated-Gabor stimuli (carrier = 1 or 4 cpd sinusoidal grating, Gaussian envelope SD = 18 arc min, 50% contrast) or a pair of Gaussian-windowed random-texture patterns that drifted vertically in opposite directions. The magnitude of the MIPS was measured for drift speeds up to 16 deg/s and for stimulus durations up to 453 ms. The temporal properties of the MIPS depended on the drift speed. At low velocities, the magnitude of the MIPS increased monotonically with the stimulus duration. At higher velocities, the magnitude of the MIPS increased with duration initially, then decreased between approximately 45 and 75 ms before rising to reach a steady-state value at longer durations. In general, the magnitude of the MIPS was larger when the truncated-Gabor or random-texture stimuli were more spatially separated, but was similar for the different types of carrier stimuli. Our results are consistent with a framework that suggests that perceived form is modulated dynamically during stimulus motion.

Keywords: Motion–form interaction; Perceived position; Dynamics of form perception; Illusion

1. Introduction

When an array of dots moves behind a stationary window of random dots, the position of the stationary motion-defined window appears to be shifted in the direction of motion (Ramachandran & Anstis, 1990). In accordance with this observation, the perceived position of a stationary Gaussian window of a Gabor stimulus also is shifted in the direction of motion of the Gabor's carrier grating (DeValois & DeValois, 1991). These illusory position shifts, along with several other phenomena in which motion influences the perceived position of a stationary object (Bressler & Whitney, 2006; Nishida & Johnston, 1999; Snowden, 1998; Whitney, 2002), suggest the presence of interactions between the specialized visual areas that encode form, position, and motion.

Many studies, using different experimental paradigms, have examined the properties of the illusory motion-induced position shift (MIPS) of stationary objects (Arnold & Johnston, 2005; Bressler & Whitney, 2006; DeValois & DeValois, 1991; Durant & Johnston, 2004; Fu, Shen, Gao, & Dan, 2004; McGraw, Whitaker, Skillen, & Chung, 2002; Mussap & Prins, 2002; Shim & Cavanagh, 2004; Sundberg, Fallah, & Reynolds, 2006; Watanabe, 2005; Whitaker, McGraw, & Pearson, 1999; Whitney, 2005; Yokoi & Watanabe, 2005). For instance, using a pair of first-order Gabor patterns with carrier gratings that drifted continuously in opposite directions, DeValois and DeValois (1991) found that the magnitude of the illusory MIPS depends both on the spatial and temporal frequency

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of the stimuli. However, they did not find a proportional relationship between the magnitude of the illusory MIPS and the carrier speed. Whitaker et al. (1999) asked observers to judge the relative size of expanding vs. contracting carrier patterns and documented an illusory motion-induced size change of the unvarying stimulus envelope. This size change could be described adequately by a square-root function of the radial carrier velocity.

Recently, Bressler and Whitney (2006) showed that the magnitude of the illusory MIPS for drifting first-order Gabor stimuli increases with the carrier velocity, before reaching a plateau that depends on the carrier spatial frequency. Using a motion-adaptation paradigm, McGraw et al. (2002) also found that the illusory position shift for a stationary first-order Gabor stimulus increases as a function of carrier speed, until leveling off at a velocity of approximately 1 deg/s.

Unlike the results of DeValois and DeValois (1991), McGraw et al. (2002) reported that the magnitude of the illusory MIPS does *not* depend on the spatial frequency of the carrier stimulus, implying that the illusory shift might depend on either the temporal frequency or the velocity of carrier motion. Indeed, the maximum position shift occurs at a nearly constant temporal frequency, for carrier gratings of both intermediate (DeValois & DeValois, 1991) and low spatial frequency (Bressler & Whitney, 2006). However, DeValois and DeValois (1991) showed that the illusory MIPS is absent if the carrier grating is flickered instead of drifting, which indicates that motion of the carrier is necessary for an illusory position shift to occur. Bressler and Whitney (2006) found that drifting second-order Gabor stimuli also exhibit an illusory MIPS. However, the temporal frequency dependence of the second-order MIPS is band-pass, as opposed to the more high-pass frequency characteristic of the MIPS that they found using first-order carrier stimuli.

The magnitude of the illusory MIPS for a drifting first-order Gabor increases monotonically with the target's retinal eccentricity, at a rate of about 1–2 arc min per degree of eccentricity (DeValois & DeValois, 1991; Fu et al., 2004). The illusion does not depend on stimulus contrast (McGraw et al., 2002) and is virtually absent if the luminance window of a drifting first-order Gabor stimulus is changed from a Gaussian to a rectangular profile (Arnold & Johnston, 2005; Whitney et al., 2003). Similarly, Ramachandran and Anstis (1990) reported that the magnitude of the illusory MIPS for a motion-defined window decreases if luminance contrast is added to the boundary between regions of moving and non-moving dots.

Recent studies suggest that the MIPS may be caused by an interaction between the processing of motion and form information (Arnold & Johnston, 2005; Whitney et al., 2003). A determination of how this illusion develops in time should produce insight into the temporal characteristics of the neural mechanisms that are involved in these interactions. Further, although it is clear that the MIPS depends on the space constant of the Gabor envelope (Arnold & Johnston, 2005; Whitney et al., 2003), it is not known how the spatial content (narrowband vs. broadband) of the carrier stimulus contributes to the magnitude of the illusion.

To investigate the *temporal* properties of the MIPS, we measured the magnitude of the perceived position shift between a pair of Gabor stimuli as a function of their drift speed, for a range of stimulus durations. To clarify the *spatial* properties of the MIPS, we measured the perceived position shift as a function of drift speed for Gabor stimuli with (1) sinusoidal carrier gratings of 1 or 4 cpd and (2) a Gaussian-windowed gray-scale random-texture pattern. Because the illusory position shift increases with the retinal eccentricity of the target (DeValois & DeValois, 1991; Fu et al., 2004), we compared the spatial and temporal properties of the illusion for two separations of the drifting stimuli. We will discuss the results in the context of possible models to describe the interactions between the processing of motion, position, and form.

2. Methods

2.1. Apparatus

Stimuli were generated on a Macintosh G3 computer using custom-written software, and were displayed on a Dell 17 in. (model M991) monitor at a mean luminance of 20 cd/m^2. The luminance of the display was measured using a Minolta LS-100 photometer. Stimuli were displayed within the central region of the monitor, measuring 26.7 deg × 20 deg. Unless otherwise stated, the video frame rate was 75 Hz. Observers sat at 65 cm from the display during testing. At this viewing distance, each pixel subtended 2 arc min.

2.2. Stimuli and psychophysical procedures

The stimuli used in Experiment 1 of this study (Fig. 1) were "Gabor" patches like those used by DeValois and DeValois (1991). Each "Gabor" was a patch of horizontal sine wave grating (the carrier) windowed by a Gaussian envelope (SD = 18 arc min). The contrast of the stimuli was 50%. In order to minimize processing time, each patch was drawn within a 1 deg × 1 deg square. At the edges of this square window, the Gaussian

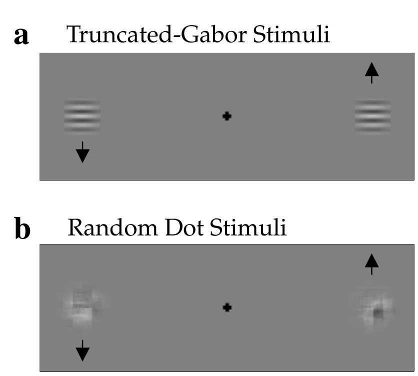

Fig. 1. Stimulus configurations for the experiments. (a) In experiments that used truncated-Gabor stimuli, a pair of horizontal sinusoidal patterns drifting vertically in opposite directions within a stationary Gaussian luminance window were presented on either side of fixation. (b) In experiments that used random-texture stimuli, a pair of random-texture patterns drifting vertically in opposite direction within a stationary Gaussian luminance window were presented on either side of fixation.